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# Generation of Accurate Frequency-Sweep Waveforms by Direct Synthesis

by

R. B. Fenwick and G. H. Barry



December 1964



Technical Report No. 99

Prepared under
Office of Naval Research Contract
Nonr-225(64), NR 088 019, and
Advanced Research Projects Agency
ARPA Order No. 196-65



RADIOSCIENCE LABORATORY

STANFORD ELECTRONICS LABORATORIES

STANFORD UNIVERSITY · STANFORD, CALIFORNIA

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## ABSTRACT

A signal whose frequency is a continuously varying function of time may be synthesized to any desired accuracy by digitally programming a "direct" frequency synthesizer. A synthesizer of this type (the Hewlett-Packard 5100A-5110A) can be modified to obtain phase-coherent frequency switching within a few hundred nanoseconds. The practicality of this mode of synthesizer operation has been demonstrated by the operation of a frequency-synthesized hf meteor radar. Two Hewlett-Packard synthesizers were modified and electronically programmed to generate 100-kc, 1-sec, linear frequency sweeps. The radar achieves close to the theoretically expected range and doppler resolutions of 1.5 km and 1 cps, respectively. It is expected that this extension of the use of frequency synthesizers for generating other than constant- or stepped-frequency signals will find many other applications where signals of precisely time-varying frequency are needed.

## CONTENTS



## ILLUSTRATIONS

# I. INTRODUCTION

A signal whose frequency is a continuously varying function of time may be accurately synthesized by digitally programming a "direct" frequency synthesizer. This technique, recently developed at the Stanford Radioscience Laboratory, thus extends the precision of frequency synthesis to a variety of applications beyond the usual fixed-frequency case.

One use of a sweep-frequency waveform is for an FM radar in which the signal frequency is a linear function of time. Any nonlinearity in the frequency has the effect of degrading the radar range and doppler resolution. Such imperfections may be reduced to insignificance through the use of a synthesized waveform. The synthesis equipment to be described was developed originally for use in an hf meteor radar having range and doppler accuracy unattainable by conventional methods of FM sweep generation.

## II. SYNTHESIS OF LINEAR SWEEPS

A variable-frequency signal may be approximated by a succession of segments, each having constant frequency. The approximation may be made as good as necessary by making the time between frequency changes so short that the piecewise constant-frequency waveform never departs significantly in phase from the ideal. In order to accomplish the frequency switching quickly and with phase coherence, it is desirable to employ a means of synthesizing each of the constant frequencies directly, without the use of phase-locked oscillators. The Hewlett-Packard 5100A-5110A synthesizer is an example of the "direct" type and was used as a starting point in the design of a sweep-frequency synthesizer. The block diagram of Fig. 1 shows the basic design philosophy.

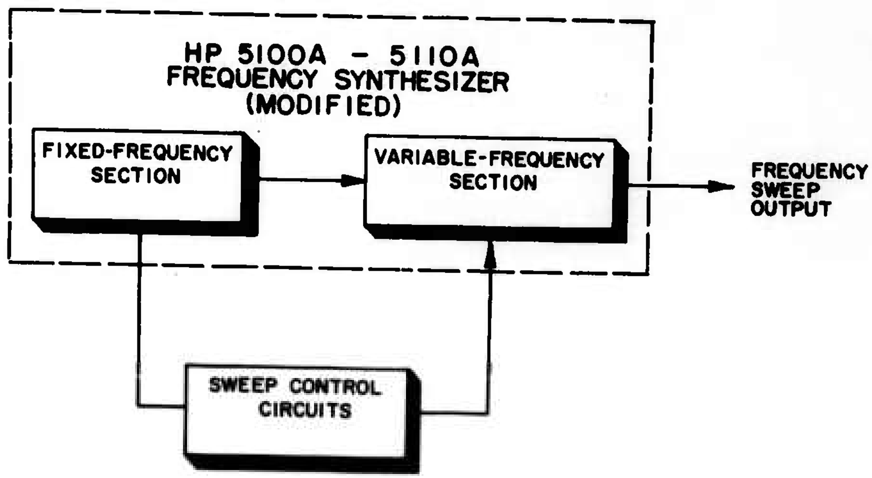



FIG. 1. SIMPLIFIED BLOCK DIAGRAM OF SWEEP-FREQUENCY SYNTHESIS EQUIPMENT.

A sweep was needed for use in an FM radar with range and doppler resolutions of 1.5 km and 1 cps, respectively. These numbers translate to a 100-kc frequency sweep in 1 sec. Figure 2a shows the desired sweep as a function of time. The staircase frequency of Fig. 2b is generated by switching in 1-cps increments every 10 μsec. A better approximation

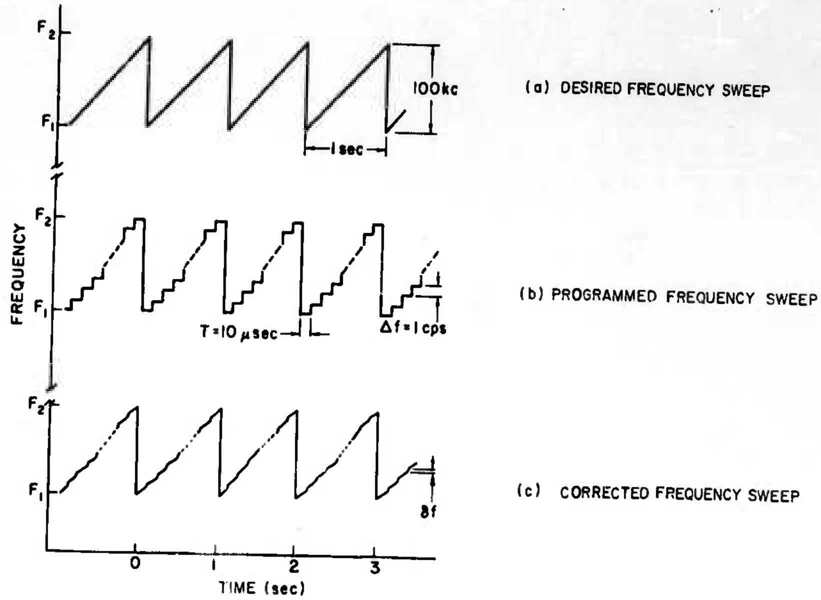



FIG. 2. IDEAL AND APPROXIMATED LINEAR FREQUENCY SWEEPS.

(Fig. 2c) could easily be obtained by adding in 1-cps frequency ramps, but such a correction is unnecessary for the hf radar application. Even the signal of Fig. 2b never departs in phase from the ideal by more than 0.0003 deg.

To electrically program the HP synthesizer requires a voltage on one wire out of ten for each of the frequency decades controlled. A 100-kc sweep in 1-cps steps then requires control of five decades (50 wires). This was accomplished by the use of five 10-element ring counters. The counters were cascaded as frequency dividers, as shown on the block diagram of Fig. 3, with the fastest counter--which controls the "1-cps" decade within the synthesizer--driven at a rate of 100 kc. The counters consist of high-speed transistor flip-flops constructed on circuit cards. Examples of the cards used are shown in Fig. 4. Figure 5 is a photograph of enough digital control circuitry to sweep eight decades of the synthesizer; only five are controlled for the present application.

Figures 1 and 3 indicate that the switching rate and times are controlled from the same frequency source that operates the synthesizer. This is necessary because of the requirement that frequency switching be

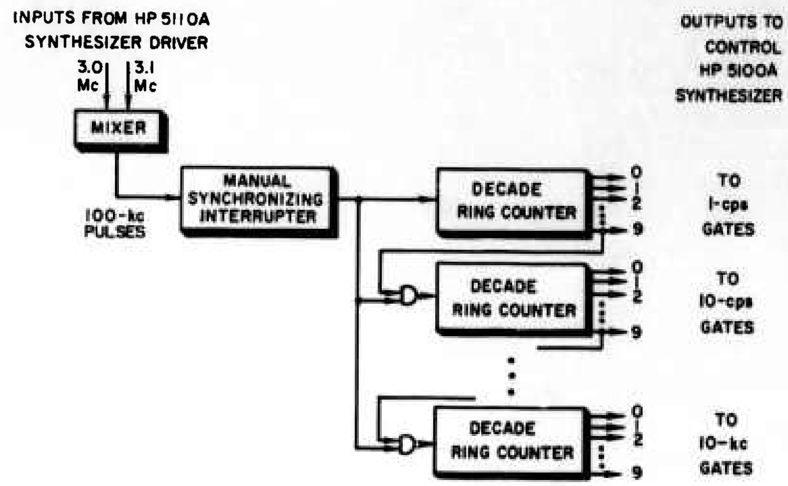
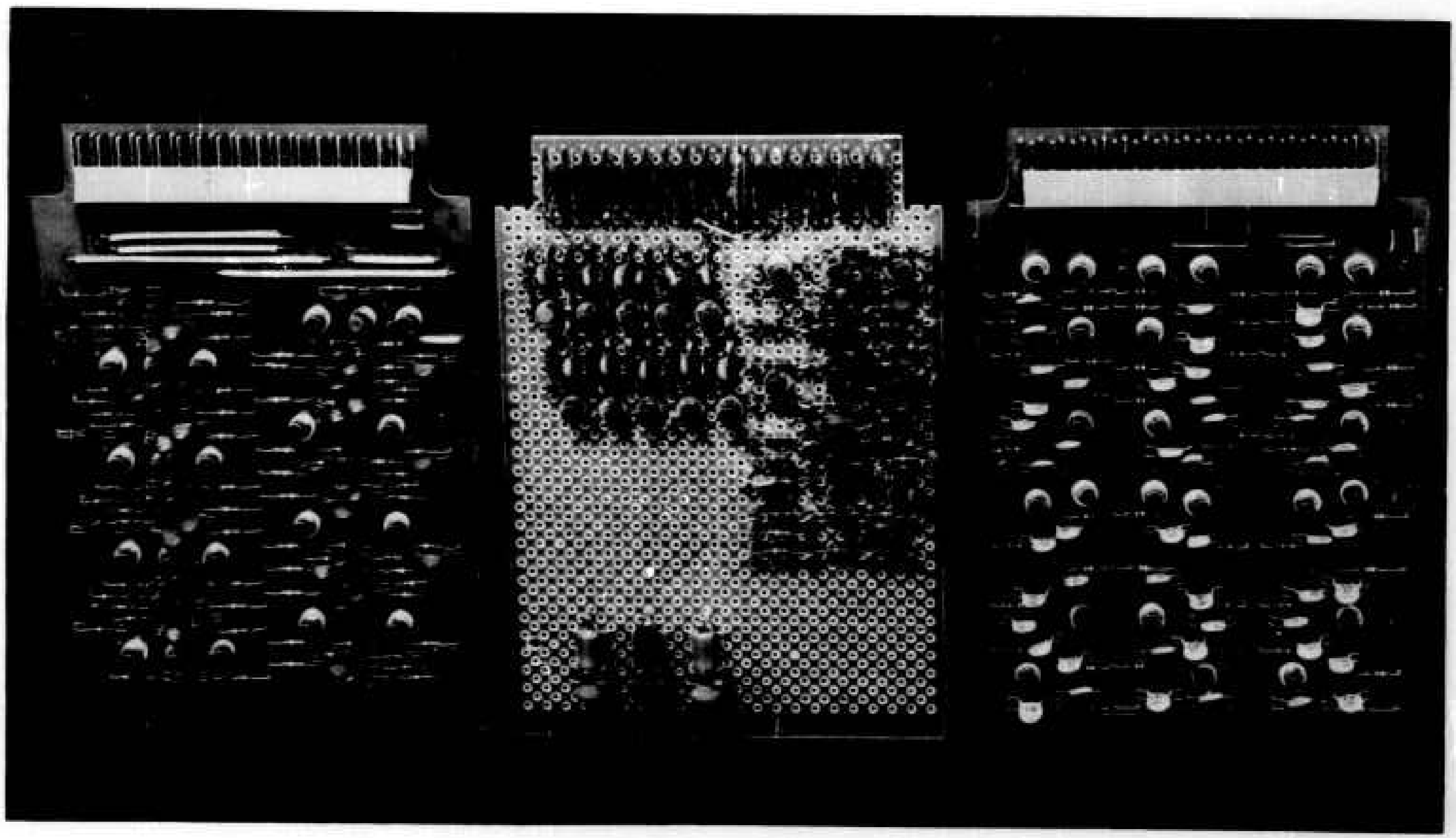



FIG. 3. BLOCK DIAGRAM OF FREQUENCY CONTROL EQUIPMENT FOR LINEAR SWEEP.

accomplished with phase coherence. The HP synthesizer derives each frequency increment by choosing one of ten signals. For frequency increments of 100 kc or less, these signals are 3.0, 3.1, ..., 3.9 Mc. The spacing between these increments (100 kc) implies that any two will be of identical phase at instants separated in time by 10 μsec. Any switching to be done must occur close to these times, otherwise the resulting phase discontinuity will produce a transient amplitude variation in succeeding tuned circuits and upset the operation of the synthesizer. These times of phase equality are determined by the frequency standard which drives the synthesizer; hence the same frequency source must be used to control the switching counters. The 100-kc counter advance for the present application was derived by mixing two of these 100-kc-spaced signals in the chassis shown in Fig. 6.

The switching time required for the HP 5100A-5110A synthesizer to settle on a new frequency is specified by the manufacturer as 1 msec, although most frequency changes are accomplished in much less time than this. However, in the present application, the synthesizer must be switched to a new frequency every 10 μsec, so it is not surprising that major modifications to the Hewlett-Packard equipment are necessary. Rapid switching raises two problems, which are discussed in the following sections.



8 Ring Stages
(5 Required)

Gate Drivers Plus
2 Ring Stages
(5 Required)

Ring Drivers
(2 Required)

FIG. 4. CIRCUIT BOARDS USED IN SYNTHESIZER CONTROL UNITS (NUMBER REQUIRED IS FOR FIVE-DECADE SWEEPING).

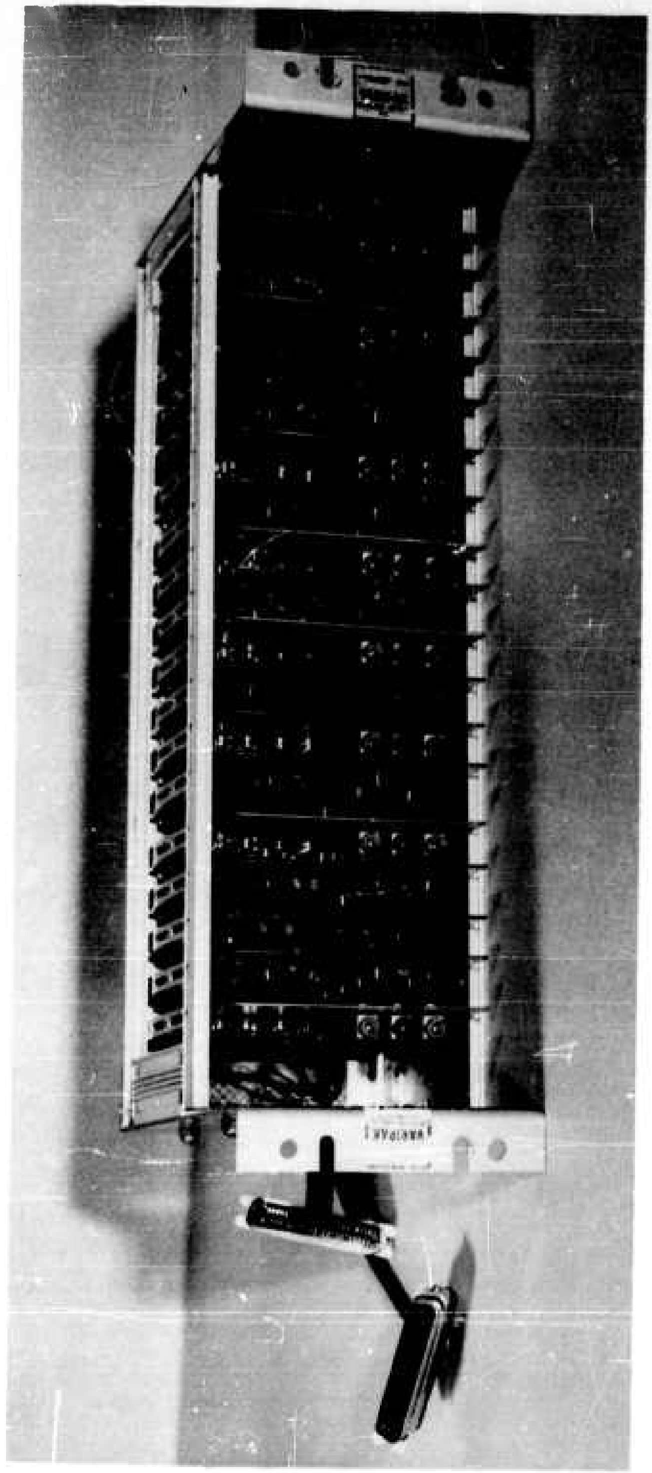


FIG. 5. PHOTOGRAPH OF DIGITAL FREQUENCY CONTROL EQUIPMENT.

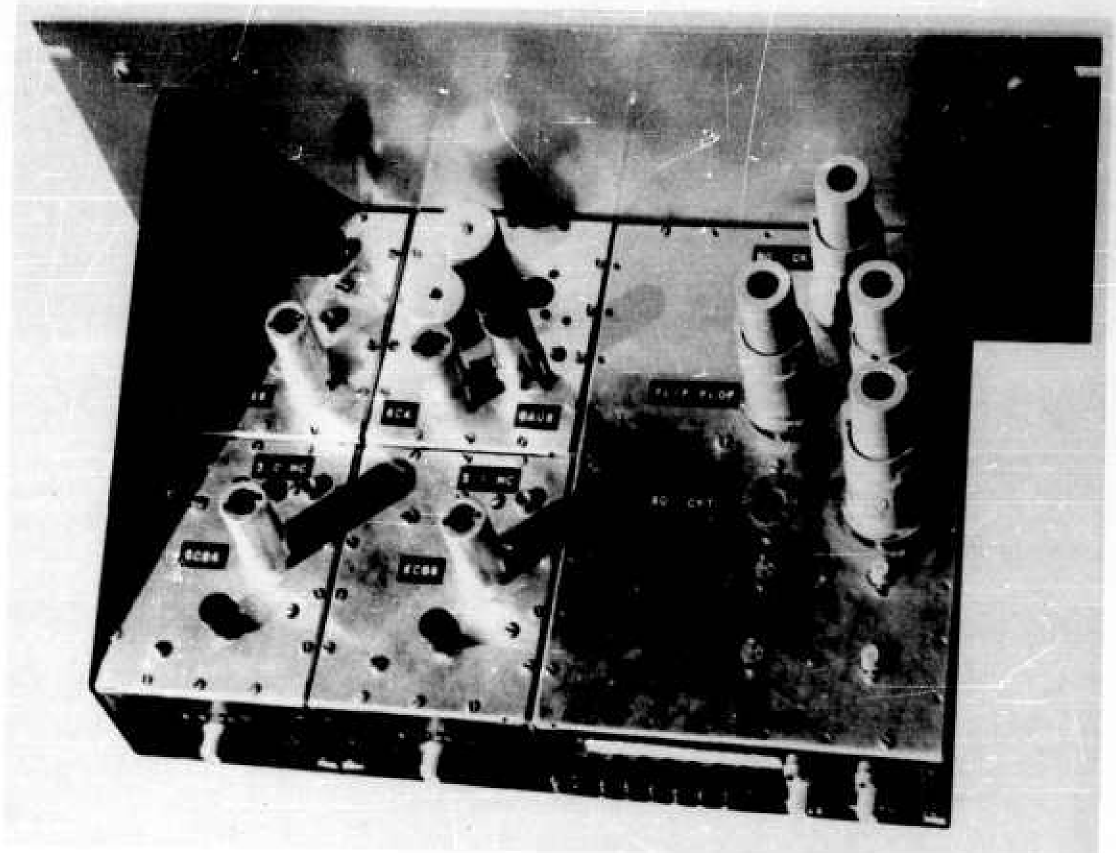


FIG. 6. COUNTER-DRIVER CHASSIS.

## A. OBTAINING PHASE COHERENCE

In the original synthesizer design, no attempt was made to obtain phase coherence among the ten signals which are pushbutton or gate selected in each of the frequency decades. Indeed, since the signals are of different frequencies, "phase equality" has no meaning unless a specific instant in time is specified, and it is generally desirable to permit frequency switching to occur at times not under the control of the synthesizer. For the sweep-frequency application, it was therefore necessary to adjust the phase of the ten basic frequencies so that all lined up in phase at desired switching times.

For the present application, it is only necessary to achieve a phase accuracy which does not result in an appreciable amplitude transient at the input to succeeding frequency divider stages. The phase adjustment is easily accomplished since each of the basic signals is derived in the HP 5110A fixed-frequency section by division from 30-39 Mc. Causing these divide-by-10 circuits to skip entire cycles (at their inputs) shifts the phase of their outputs in one-tenth-cycle increments; this is a sufficiently fine adjustment. A switch for interrupting the divider operation on nine of the ten basic frequencies was installed on the 5110A front panel (see Fig. 8, pages 11 and 12).

## B. OBTAINING FAST FREQUENCY SWITCHING

In addition to achieving phase coherence at the instants of frequency switching, it is necessary to accomplish the actual signal gating rapidly (compared to the period of the chosen frequencies, 3.0 to 3.9 Mc). Gates within the HP 5100A synthesizer were not designed with this requirement in mind, and it is necessary to 1) remove all blocking and bypass capacitors associated with these gates in order to shorten their transient response, and 2) install emitter followers in the ten signal lines to provide low-impedance signal sources for the gates. The redesigned gates have a switching time on the order of 200 nsec. These modifications have the disadvantage that they degrade the spurious signal suppression to only about -40 db, a figure which may not be satisfactory in some applications. This aspect of performance could be improved, but not without major redesign of the synthesizer frequency-gating circuits.

## III. USE IN HIGH-FREQUENCY FM RADAR

Frequency modulation has been widely employed in radars since its use makes possible the transmission of powers several orders of magnitude greater than may be obtained in straightforward short-pulse operation, thus increasing radar range. Reduced to simplest terms, continuous-wave FM radar operation against a stationary target involves two operations:

1. Transmitting a linear ramp of instantaneous frequency vs time, and
2. Mixing the delayed "echo" ramp energy with the outgoing ramp in a receiver, resulting in a beat note in the receiver output whose frequency is directly proportional to target range.

Thus the range resolution is limited by the accuracy to which the received beat frequency can be measured. This ability, in turn, depends upon the length of time the beat frequency is available for measurement (related ultimately to sweep width) and the extent to which it remains constant throughout the sweep. For a constant-frequency beat note, the frequency ramp must be absolutely linear. This fact motivated the development of the presently described system.

The complete FM radar system, which employs the sweep-frequency synthesizer, is shown in the block diagram of Fig. 7. To observe short-range targets using a 1-sec transmission requires that transmitting and receiving equipment be separated by a distance sufficient to reduce direct signals between the sites to an acceptably low value. Thus, two synthesizers are required, one at the transmitting site and one at the receiving site.

At the transmitting site, the synthesizer output is amplified to the desired power level using an ordinary class C hf transmitter. The received signal is translated to the i-f of a normal communications receiver using the second synthesizer as a local oscillator. Time synchronization of the two synthesizers is accomplished at the receiver site by interrupting the counter advance line for short, calibrated times until the desired sweep alignment is achieved.

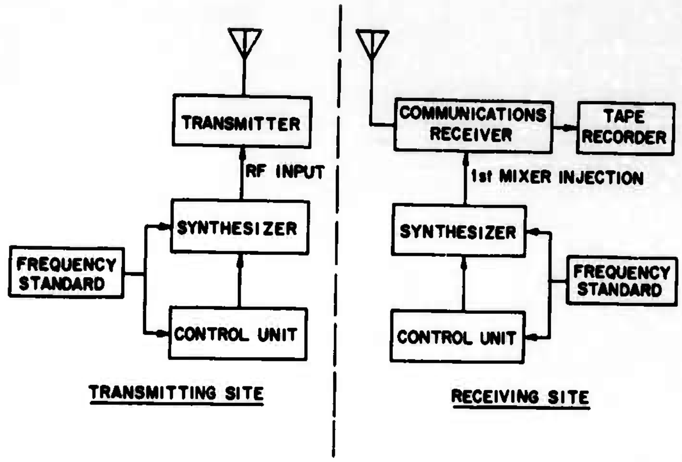
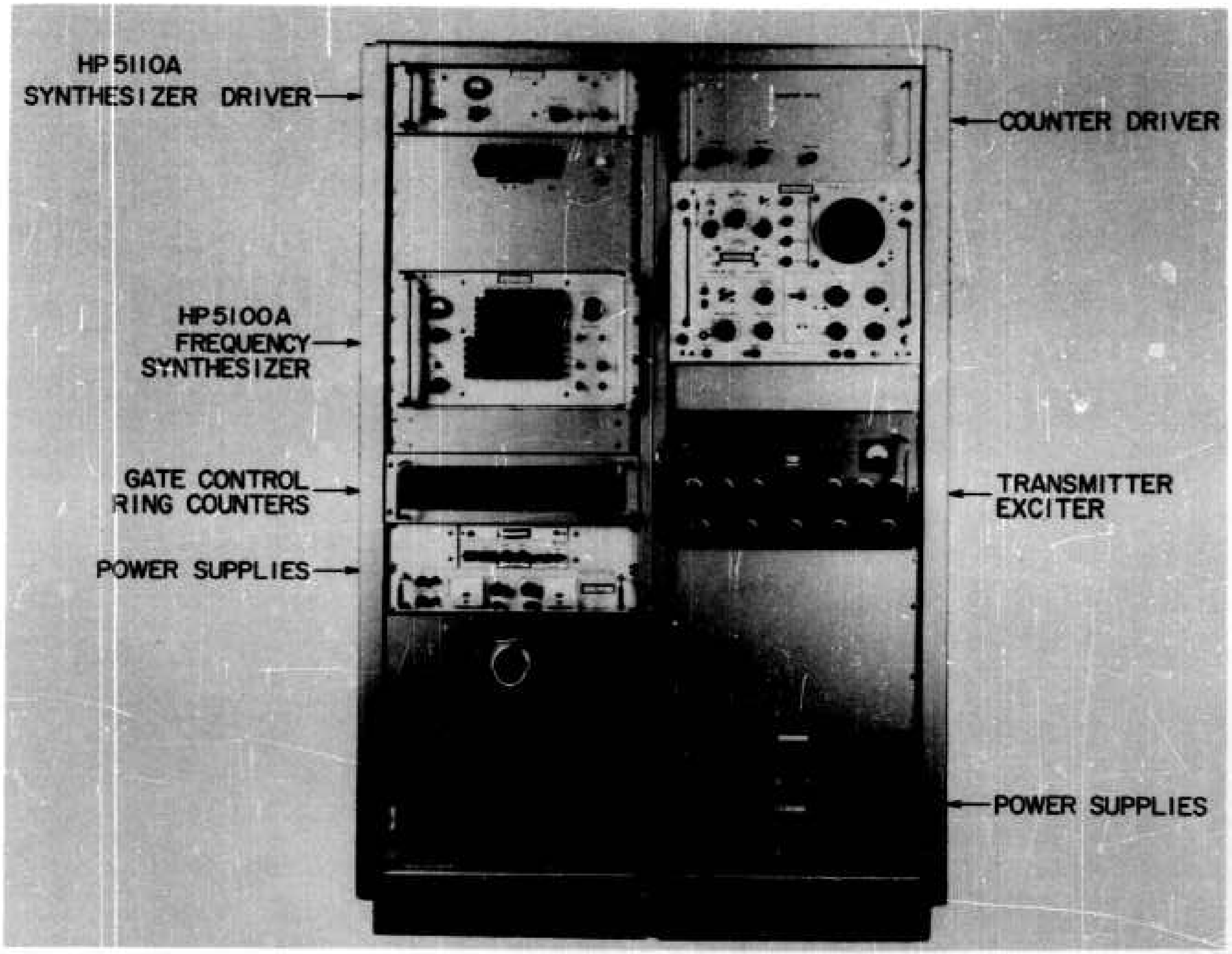



FIG. 7. SIMPLIFIED BLOCK DIAGRAM, FM RADAR SYSTEM.

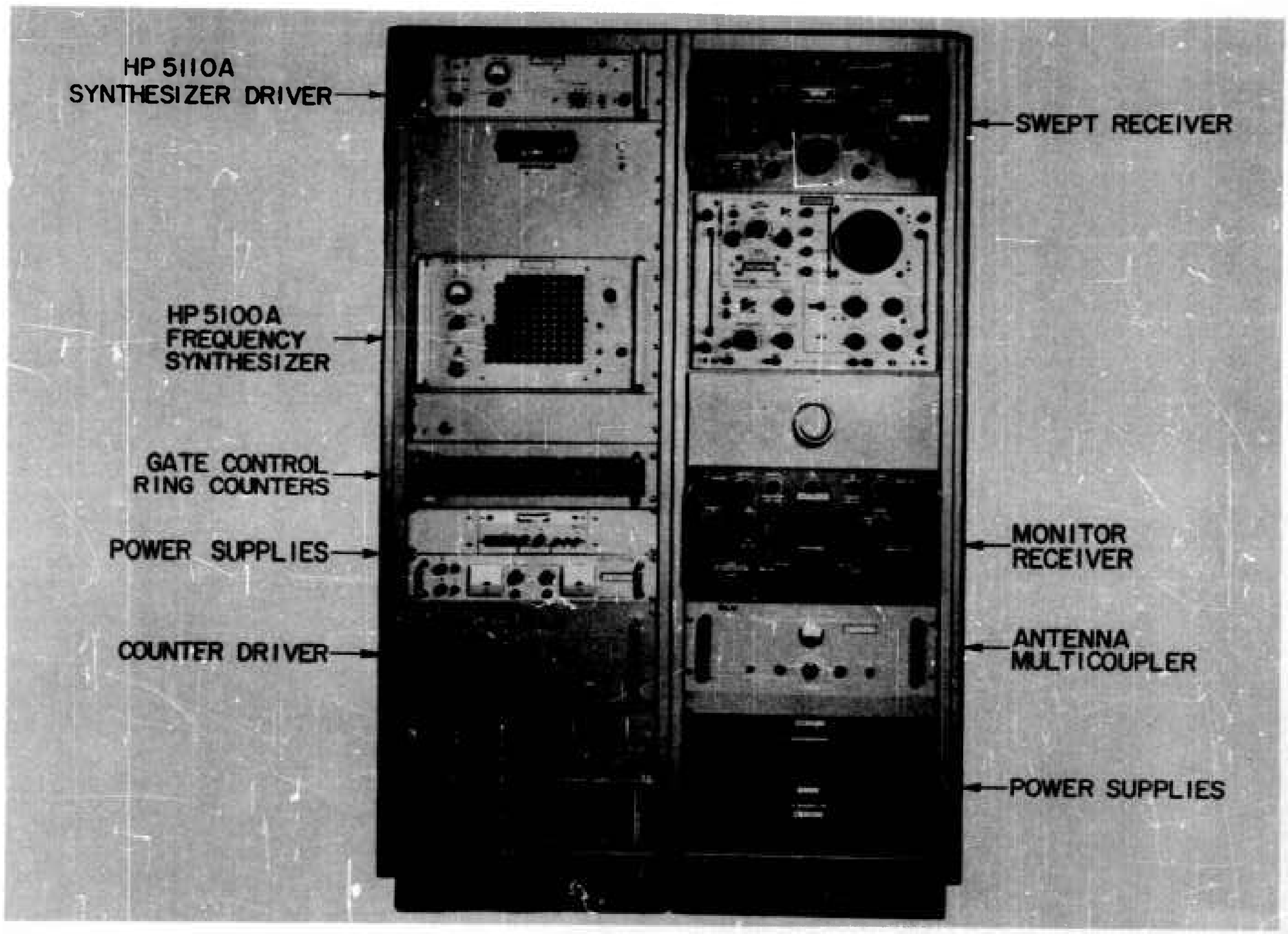
The photographs of Fig. 8 show complete transmitting and receiving systems, except for the hf transmitter final amplifier. A second receiver is included for band monitoring while the equipment is in operation. The oscilloscopes are needed primarily for accomplishing the phase adjustment within the synthesizers, a task which requires only a minute but must be repeated each time the HP 5110A synthesizer driver is turned on (hence, it is normally left on).

Figure 9 shows two range-plus-doppler vs time records made with the cw, FM radar. A 500-w transmitter was employed; three-element beam antennas were used for both transmitting and receiving. The records were produced by spectrum analysis of the receiver-detector output voltage. Figure 9a shows echoes from meteors (approximately 60 per minute), while Fig. 9b shows backscatter from the ground following an ionospheric reflection. Tests have shown that the theoretical resolutions of 10 $\mu$sec and 1 cps have been closely approached. The radar sensitivity is comparable with that of a cw system employing a 1-cps bandwidth.



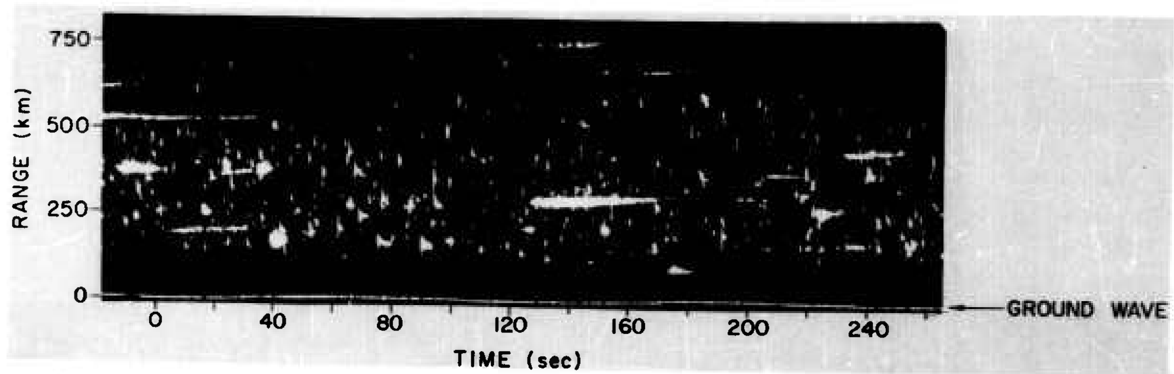

a. Transmitting system

FIG. 8. FM RADAR TRANSMITTING AND RECEIVING SYSTEMS.

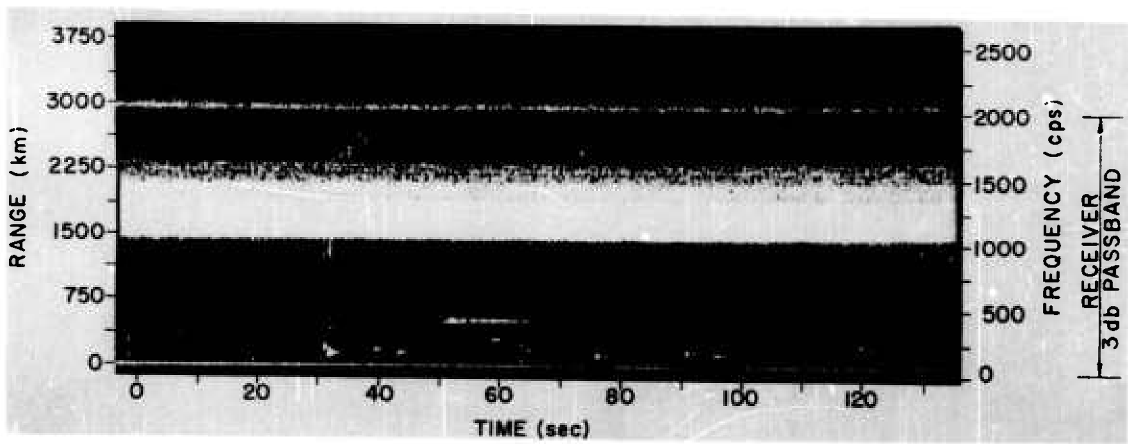



b. Receiving system

FIG. 8. FM RADAR TRANSMITTING AND RECEIVING SYSTEMS.




a. Meteor echoes




b. Backscatter

FIG. 9. RANGE-DOPPLER VS TIME RECORDS MADE WITH THE CW, FM RADAR SYSTEM. (Obtained at San Luis Obispo, Calif., November 1964; 100-kc/sec sweep rate, 17-Mc frequency, 500-w transmitter, 270 deg azimuth.)

## IV. CONCLUSIONS

The usefulness of commercially available, direct-frequency synthesizers may now be extended for applications other than the generation of constant- or stepped-frequency signals. Signals of continuously varying frequency may be approximated to considerable accuracy by rapidly programming such a synthesizer. It is expected that many applications will arise for signals of precisely time-varying frequency; the technique has already proved successful in generating linear frequency sweeps for use in FM radar.

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